



Technical Paper

Title: Properly Implemented Investigation and Integrity Testing of Augered Cast-In-Place Piles Saves a Costly Structure - A Case History

Authors: D.S. "Sax" Saxena, P.E.
Anupam Saxena, P.E.
Gregory Stephan, P.E.
ASC geosciences, inc., Lakeland, Florida, USA

Date: 20-22 October 1997

Publication/Venue: 50th Canadian Geotechnical Conference, Ottawa, Canada

ASC Paper ID: 1997-02

PROPERLY IMPLEMENTED INVESTIGATION AND INTEGRITY TESTING OF AUGERED CAST-IN-PLACE PILES SAVES A COSTLY STRUCTURE - A CASE HISTORY

Gregory A. Stephan, P.E., Anupam Saxena, P.E., and D.S. "Sax" Saxena, P.E.
ASC geosciences, inc., 3055 Drane Field Road, Lakeland, Florida, USA

ABSTRACT

Unsupervised and questionable augered cast-in-place (ACIP) pile installation procedures used by the specialty contractor raised doubts about the structural integrity of the installed foundation support system for a project in Naples, Florida, USA. Removal/replacement of the installed piles was considered a viable yet costly option. Visual inspection survey and low-strain integrity tests were conducted on all piles, utilizing a Pile Integrity Tester (PIT).

In the absence of an effective quality control installation monitoring program, PIT was employed as an acceptable method for post-installation evaluation of anomalies in the installed auger-cast piles. Sonic integrity test profiles and available installation records indicated anomalies ranging from voids, necking, bulging, to soil inclusions in the grout. As many as 15 (50 percent of the installed piles) were determined to be questionable and could not be rated for the desired capacity. Examination of a few excavated piles showed some anomalies not clearly defined by the sonic integrity test records. Acceptable rated capacities for each of the questionable piles were used and the foundation plan subsequently modified.

This case history confirmed that project team members were knowledgeable professionals who could rationally assess the risks involved and were not opposed to innovation as a means of reducing costs and achieving economy. Furthermore, this experience shows the reliability of sonic integrity testing can be improved by supplementing it with a carefully implemented pile installation monitoring program.

RÉSUMÉ

Unsupervised et jet-in-endroit du augered contestable procédures de l'installation du pieu d'occasion a évoqué par l'entrepreneur de la spécialité des doutes au sujet de l'intégrité structurelle de l'a installé le système du support de la fondation pour un projet dans Naples, Florida, USA. Enlèvement/ substitution de l'a installé des pieux a été considéré un viable cependant option chère. Inspection de l'inspection visuelle et épreuves de l'intégrité du bas-tension ont été conduites sur tous pieux, utilise un Vérificateur de l'Intégrité du Pieu (PIT).

Dans l'absence d'un programme de l'écoute de l'installation du contrôle de la qualité efficace, PIT a été employé comme une méthode acceptable pour évaluation du poteau-installation d'anomalies dans l'a installé des pieux du tarière-jet. Sonic profils de l'épreuve de l'intégrité et registres de l'installation disponibles ont montré des anomalies aligne d'annule, pelotage, ballonnement, souiller des inclusions dans le coulis. Comme beaucoup de comme 15 (50 pour cent de l'a installé des pieux) a été déterminé être contestable et ne peut pas être estimé a désiré pour le la capacité. Examen de quelqu'a détéré des pieux monde du spectacle quelque les anomalies ont défini pas clairement par les registres de l'épreuve de l'intégrité du sonic. Acceptable a estimé capacités pour chaque des pieux contestables ont été utilisées et le plan de la fondation a modifié plus tard.

INTRODUCTION

Development and installation of augered cast-in-place (ACIP) piles in connection with the expansion of a restaurant building along an inland waterway provided construction challenges resulting from site geometry, space limitations, and project time constraints. Cloyde's Steak and Lobster House, a 1-story restaurant building which is part of a larger beachfront commercial shopping center, is located off Park Shore Drive in Naples, Collier County, Florida, as illustrated in Figure 1.

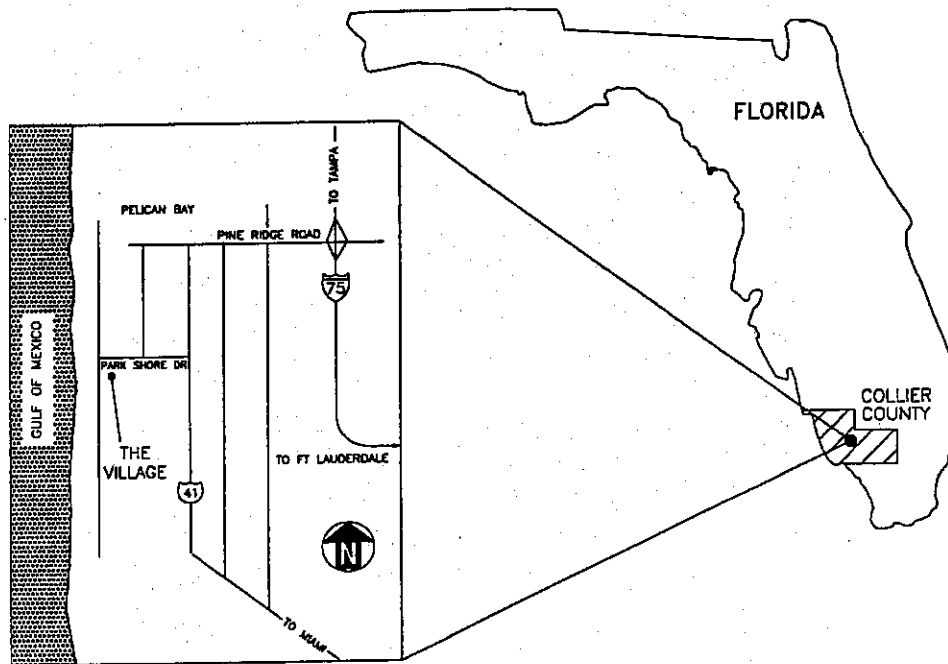


FIGURE 1. Site location map.

Construction of a 1-story addition to the existing restaurant building included foundation support 30-cm diameter ACIP piles installed to a depth of 7.6 m as per the pile layout plan illustrated in Figure 2.

ASC geosciences, inc. was retained to develop an investigative project scope of services only upon notification that the ACIP piles were being installed without any quality control monitoring measures which typically form a key element of the overall approval and acceptance process (Saxena 1995). In the absence of these traditional quality control measures and concerns about the quality of installed piles, the investigation included the elements listed below

- a. non-destructive testing (NDT) and profiling of the installed ACIP piles utilizing a Pile Integrity Tester (PIT);
- b. employing PIT as an acceptable method for post-installation non-destructive evaluation of anomalies in installed ACIP piles; and,
- c. compilation of field testing data and preparation of a NDT evaluation report.

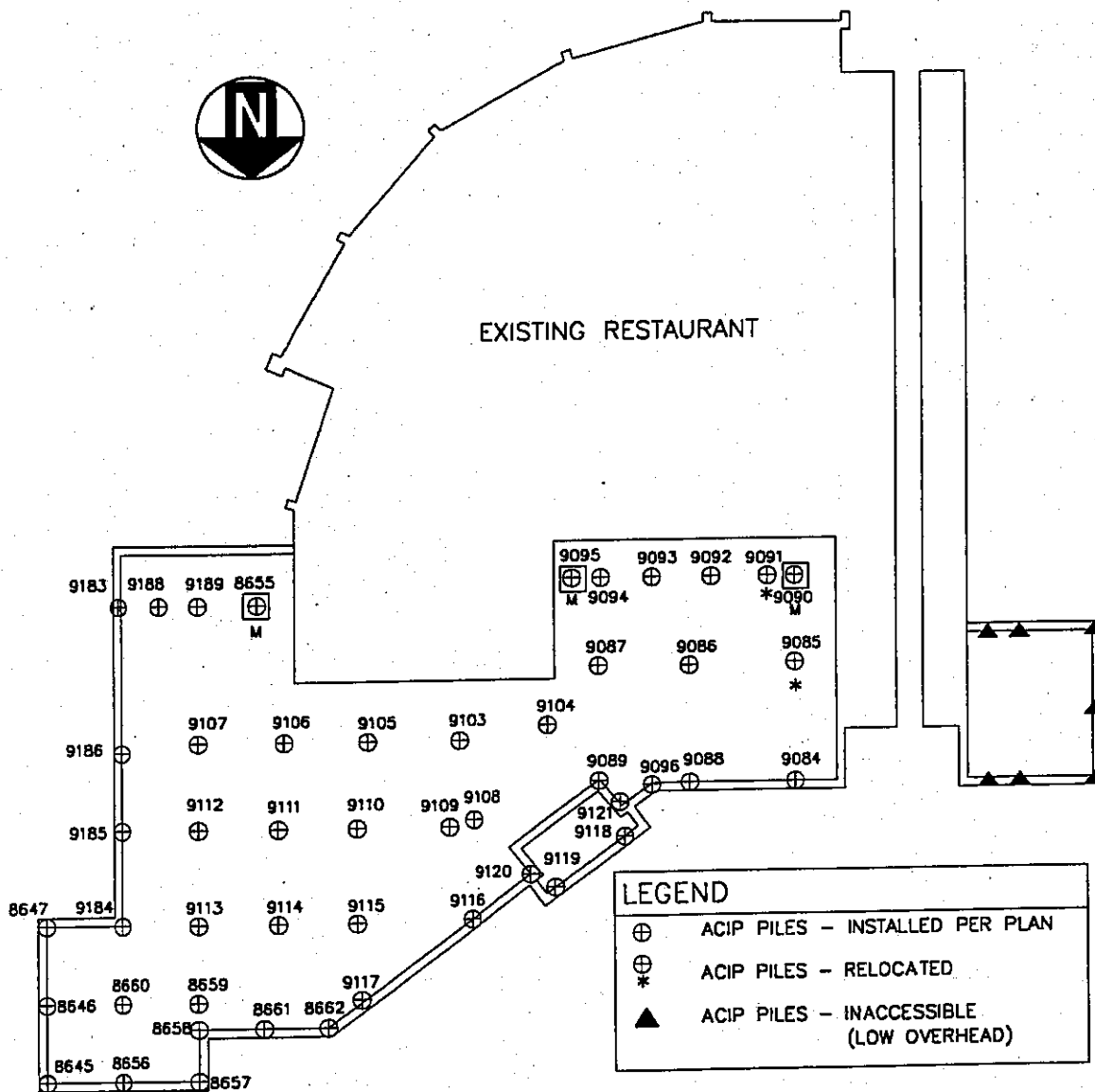


FIGURE 2. Pile layout plan.

TESTING EQUIPMENT

Four major devices are used to perform a PIT test: i) a small hand-held instrumented impact device (hammer); ii) a sensitive accelerometer; iii) a special purpose PIT data collector (PIT FV); and, iv) an output device. Depending on the pile size and length, different size hammers which consist of a wooden handle and plastic cushions may be used. Smaller hammers impart a higher frequency content with lower energy delivered to the pile top and, therefore, smaller hammers are usually preferable. However, as the wave frequencies increase for smaller hammers, more energy is lost in the wave propagation and the ability of investigating a longer pile diminishes. For this reason it is preferable to conduct the PIT test using different hammer sizes. Smaller hammers produce more detailed pile properties while the larger hammers generate a better pile toe reflection. The PIT-FV collector provides signal conditioning, stores data which can be transferred to a computer for later analyses, performs calculations for data interpretation, and sends data to a plotter or a laser printer. The equipment is powered with a rechargeable battery.

TESTING PROCEDURE

Proper preparation of the ACIP pile top surface is an important part of any PIT test. It may be necessary to remove or grind off a few inches of the upper concrete if it has been contaminated with soil or if it consists of poor quality concrete. Once a clean and hard concrete surface has been prepared, the accelerometer is attached to the pile top surface with a thin layer of a soft viscous material. Downward, compressive impact waves are then generated by striking the pile top with the hand-held hammer several times. The pile top motions and hammer impact forces are then captured by the PIT-FV collector which digitizes the data records and then displays a signal on screen for each blow. Selected velocity and force records are averaged. The engineer may then review the velocity and force curves for signs of any reflections. The averaged velocity record on the PIT screen shows the effects of the impact pulse along with reflections from either pile anomalies or the pile toe itself. The reflection from the pile toe is sometimes difficult to interpret. In these cases, the signal can be exponentially amplified with time. By amplifying the velocity records with time, toe reflection often can be more clearly displayed. An unclear toe signal even after using a large hammer and applying a high amount of amplification, indicates inconclusive blow data.

DATA INTERPRETATION

Collected data records are downloaded from the PIT-FV collector to a computer for permanent storage and further analyses. The evaluation and interpretation of the data records, however, requires extensive wave analyses using the PITWAP program (Pile Integrity Testing Wave Analysis Program developed by Pile Dynamics, Inc.). Naturally, data interpretation is one of the most important steps in the PIT testing operation.

PITWAP is a wave equation analysis program using either a measured force or an assumed force, which is proportional to the velocity during the early impact time, as input. The program calculates the pile top velocity and compares it to the measured one. If these two curves do not agree, the pile model is adjusted, and the analysis repeated until a best match is achieved. The signal matching technique is virtually automated. Results of the PITWAP program are expressed in terms of impedance which is a function of the pile cross-sectional area, modulus of elasticity of concrete, and wave speed of the pile materials. Variations in these factors result in impedance variations. It should be noted that the soil resistance effects the results of the PIT test records. The soil resistance effects are not clearly defined, and for that reason the engineer must exercise judgment in evaluating the results. A strong knowledge of and experience with one-dimensional wave propagation as well as pile installation procedures and subsurface conditions is therefore preferred.

The output of the PIT is a graph of signal versus pile length. Piles with flawless shafts will simply indicate a reflection from the pile toe whereas defective piles or piles with anomalies will exhibit an early reflection from the flawed location. It must be emphasized that the sensitivity of the PIT is such that even a minor defect (internal or external) will exhibit an early reflection. The various types of defects or anomalies include pinching, necking, bulging, the presence of soil pockets or inclusions, or an internal void. Furthermore, internal voids can occur at locations from reflection where the exterior pile surface appears normal.

Based on a review of the limited pile installation records and observations from our field investigation, it was concluded that most of the installed ACIP piles at the project site exhibited either internal voids, grout contamination, or change in composition of grout (i.e., sand pockets).

POST-INSTALLATION TESTING

Unexpected events such as the absence of any grout pressure measuring gage and the inconsistent rate of pile installation (rate of insertion and withdrawal of the flight auger) had raised questions regarding the soundness of installed ACIP piles. The integrity testing of cast-in-place structural elements using sonic test methods is an accepted quality assurance method in most construction. For cast-in-place deep foundations such as piles and caissons, several methods are available. They include visual examination of exhumed shallow castings, proof by coring, and interpretative non-destructive testing. The methodology employed depends on the overall confidence in the test method itself, its applicability for the specific project, experience, and cost (Mirza et al. 1994).

In the absence of an effective quality control installation monitoring program and limited inspections during installation, the PIT was selected as an investigative tool by all project team members. During the period from 30 September to 3 October 1996, low-strain sonic integrity tests utilizing the PIT-FV collector were performed on a total of 44 installed ACIP piles. Typical plots of 3 pile types are illustrated in Figure 3.

The PIT profiles do not indicate minor defects in the ACIP piles. However, major (>5 to 10 percent) necking, bulging, or cavities themselves in the pile can be easily detected when the velocity profiles shows either negative or positive impedance. The large negative impedance in the shape of v-shaped dips at the beginning and end of the profile are normal. In a good pile, the impedance between these 2 dips remains constant, as indicated in the upper profile of Figure 3. The middle profile illustrates a questionable impedance caused by the presence of separation or soil inclusions in the pile shaft. The lower profile exhibits a positive impedance caused by a neck or bulge in the pile shaft.

NON-DESTRUCTIVE EVALUATION RESULTS

The PIT testing indicated that a number of the piles exhibited characteristics of anomalies such as internal voids, necking, bulging, soil inclusions in the grout, etc. Based on this information coupled with the absence any of quality control testing measures, the integrity of these piles was considered to be out of tolerance with project plans and specifications and, therefore, questionable. As many as 50 percent of the installed ACIP piles could not be rated for the required design capacity.

A summary of each installed ACIP pile is presented in Table 1 and includes the depth to anomaly, where observed, as well as remarks regarding the pile acceptance or rejection. For piles exhibiting marginal flaws, a revised capacity rating was recommended for incorporation by the project structural engineer and is also listed in Table 1.

CONCLUSIONS

Following completion of all services and discussion amongst the project team members, several conclusions were drawn for this project.

- ▶ The specialty contractor's offer of load testing a select few piles was not considered acceptable due to the large number of questionable piles.
- ▶ PIT is a useful and relatively inexpensive tool which assists in the evaluation of construction quality and provides some degree of assurance about the integrity of ACIP piles. It served this project well for evaluation of the ACIP piles (30-cm in diameter installed to depths of roughly 7.6 m).
- ▶ The integrity of the ACIP piles are highly dependent on the skill of the specialty contractor's field personnel. Accordingly, specialty subcontractors should be pre-qualified with respect to experience and quality (Saxena 1995).
- ▶ It appears that the sonic technique may not be reliable enough to be regarded as a stand-alone measure used to evaluate the integrity of ACIP piles (Samman and O'Neill 1996). However, taken with other available installation data, the PIT test can provide information which may be utilized to rationally determine the integrity of an ACIP pile and if a damaged pile must be removed/replaced (Abar 1994).

ACKNOWLEDGMENT

The opportunity to perform the services described herein provided an interesting exercise in the planning and execution of this unique investigation. The information herein is from a project where the authors and their firm, ASC geosciences, inc. were involved as the geotechnical engineering and testing consultant. ASC expresses its appreciation to the other project team members: Walter L. Keller and Associates., P.A., project architect; The Lutgert Companies, owner/developer; and Boran Craig Barber, the general contractor, all from southwest Florida.

REFERENCES

- Abar, N. 1994. Pile Integrity Testing in North Carolina, Proceedings, International Conference on Design and Construction of Deep Foundations, Orlando, Florida, December 1994, Vol. III, pp. 1244-1261.
- Mirza, C., and Montgomery, M. 1994. Load and Integrity Testing of Augercast Piles for a Multi-Level Building, Proceedings, International Conference on Design and Construction of Deep Foundations, Orlando, Florida, December 1994, Vol. III, pp. 1262-1271.
- Samman, M.M., and O'Neill, M.W. 1996. An Exercise in Seismic Testing of Drill Shafts for Structural Defects, Association of Drilled Shaft Contractors, December/January 1997, pp. 11-17.
- Saxena, D.S. 1995. Designed, Tested and Installed Auger-Cast Pile Foundation - A Case Study, Proceedings, Xth Pan American Conference on Soil Mechanics and Foundation Engineering, Guadalajara, Mexico.

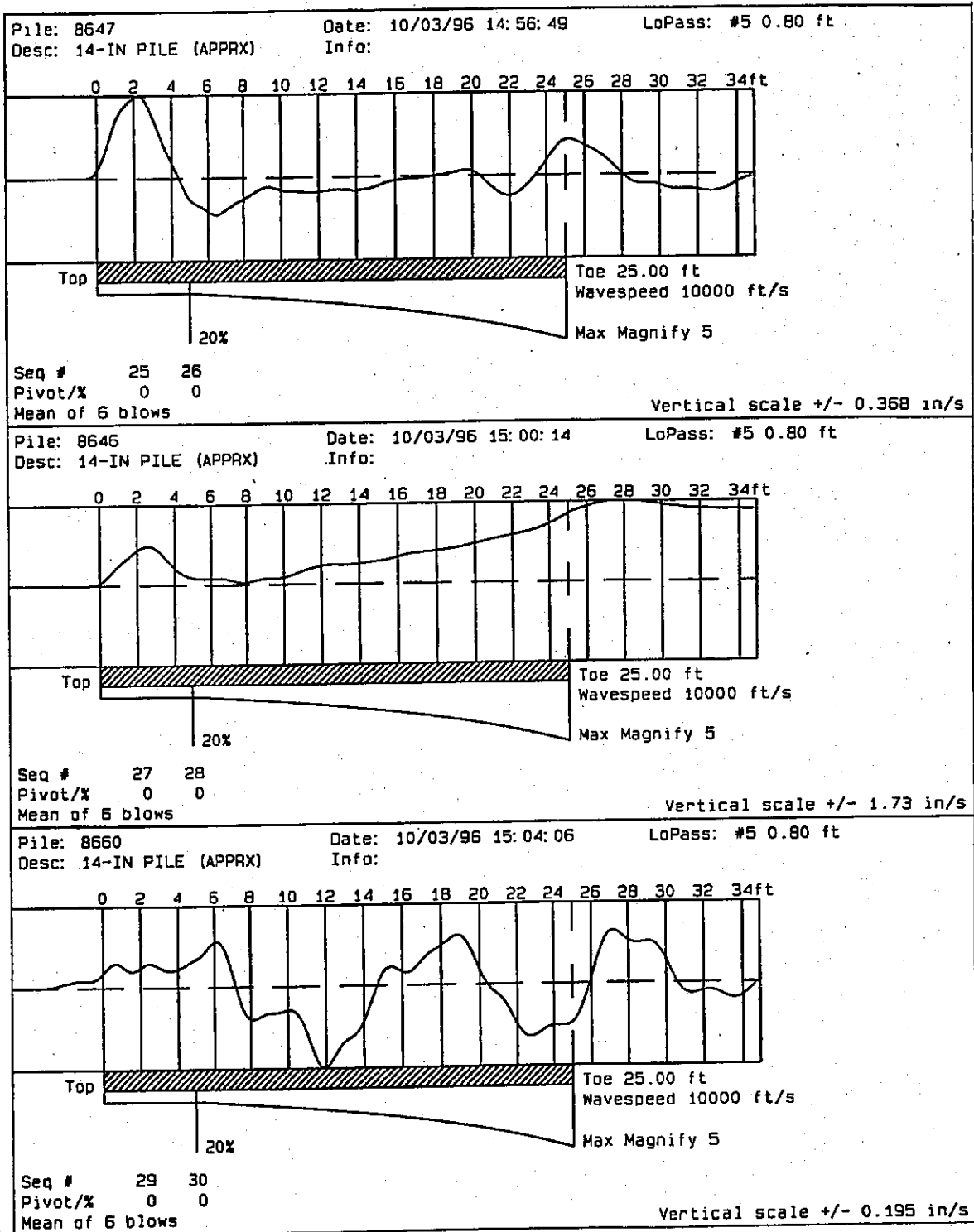


FIGURE 3. Typical velocity and force records (PITPLOT) for accepted, rejected, and re-rated piles.

TABLE 1. Summary of pile integrity testing and anomalies

| AS-BUILT SURVEY PILE NO. | ALLOWABLE CAPACITY | | DEPTH TO ANOMALY (m) ¹ | REMARKS |
|--------------------------|-----------------------------|------------------------------|-----------------------------------|----------------|
| | RATED BY STRUCT ENGR (kips) | RATED BY GEOTECH ENGR (kips) | | |
| 8645 | 12 | 12 | 6, 22 | accept |
| 8646 | 16 | 10 | 10 | revised rating |
| 8647 | 12 | 12 | 6, 22 | accept |
| 8656 | 15 | no good | 6 | reject |
| 8657 | 11 | 11 | 16 | accept |
| 8658 | 18 | 12 | 6 | revised rating |
| 8659 | 7 | 7 | 10 | accept |
| 8660 | 14 | no good | 8, 12, 22 | reject |
| 8661 | 16 | 16 | 6 | accept |
| 8662 | 16 | 16 | 6 | accept |
| 9084 | 18 | 18 | 4 | accept |
| 9085 | 19 | 19 | 5, 21 | accept |
| 9086 | 19 | 10 | 3, 6, 10 | revised rating |
| 9087 | 16 | 16 | 15 | accept |
| 9088 | 17 | 17 | 4 (minor) | accept |
| 9089 | 16 | 16 | 19 | accept |
| 9091 | 15 | 15 | 6 ² | accept |
| 9092 | 19 | 12 | 5 ² | revised rating |
| 9093 | 19 | 16 | 19 ² | revised rating |
| 9094 | 15 | no good | 6 ² | reject |
| 9096 | 14 | 14 | 5 (minor) | accept |
| 9103 | 17 | no good | 5, 10, 14, 21 | reject |
| 9104 | 13 | 13 | 5, 22 | accept |
| 9105 | 20 | no good | 5, 7 | reject |
| 9106 | 19 | no good | 7, 15 | reject |
| 9107 | 18 | no good | 4 | reject |
| 9108 | 20 | 20 | 7, 23 | accept |
| 9109 | 20 | 8 | 6, 22 | revised rating |
| 9110 | 18 | 12 | 10, 22 | revised rating |
| 9111 | 17 | no good | 10, 22 | reject |
| 9112 | 16 | 16 | 7, 22 | accept |
| 9113 | 18 (est) | 18 | 5 | accept |
| 9114 | 18 (est) | no good | 6, 10 | reject |
| 9115 | 17 | no good | 8 | reject |
| 9116 | 20 | 12 | 6 | revised rating |
| 9117 | 16 | 16 | 6 | accept |
| 9118 | 14 | no good | 3, 21 | reject |
| 9119 | 18 | 18 | 5, 22 (minor) | accept |
| 9120 | 15 | 10 | 16 (minor) | revised rating |
| 9121 | 15 | 15 | 5 | accept |
| 9183 | 20 | 20 | 4 (minor) ² | accept |
| 9184 | 20 | no good | 4 | reject |
| 9185 | 17 | 17 | 5 (minor) | accept |
| 9186 | 14 | no good | 6 | reject |
| 9188 ³ | 19 | no good | --- | reject |
| 9189 ³ | 16 | no good | --- | reject |

NOTES: ¹ Depths indicated are from top of existing pile and are only approximate. Anomaly could result from internal voids, contamination of grout, necking, bulging, soil pocket, pinching)
² Piles were installed shorter than 7.6 m; depth noted is approximate depth of installation
³ Grout contamination in upper portion of pile; no PIT signal observed
⁴ Internal voids may exist at locations from reflection points where exterior surface looks normal